

The background of the entire slide is a composite image of space. On the left, a large, detailed Earth's moon is shown. Above it and to the left is a smaller, reddish planet, likely Mars. A small rocket is depicted in the center, moving from the moon towards the right, leaving a bright blue trail. The sky is a deep blue with numerous white stars. In the bottom right, there is a black silhouette of a person's head and shoulders, looking towards the left. The bottom of the image shows a dark, silhouetted horizon line.

EXPLORESPACE TECH

TECHNOLOGY DRIVES EXPLORATION

GO: Advanced Propulsion
NASA Space Technology Mission Directorate
March 2022

STMD welcomes feedback on this presentation
See RFI 80HQTR22ZOA2L-GO at nspires.nasaprs.com for how to provide feedback
If there are any questions, contact HQ-STMD-STAR-RFI@nasaprs.com

SPACE FLIGHT ARCHITECTURE DOMAINS

Exploration, Science, Commerce & Security



LEO TO CIS-LUNAR CLPS/ARTEMIS & CIS-LUNAR DEVELOPMENT

- ❖ Science Payloads
- ❖ Mining & Resource Extraction
- ❖ Manufacturing
- ❖ Fuel Depots / In Situ Derived Prop
- ❖ Space Solar Power
- ❖ Outposts (In-Space & Surface)
- ❖ Orbital Debris Mitigation and Remediation
- ❖ Planetary Defense Assets
- ❖ National Security Space Assets

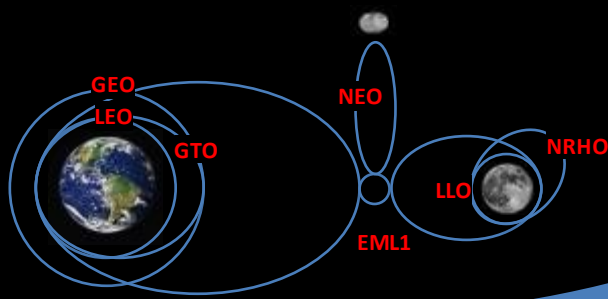
MESO-SOLAR MOON-TO-MARS & EXPANDING SCIENCE/EXPLORATION

- ❖ Humans on Mars
- ❖ Search for Life
- ❖ Sample Return
- ❖ Outer Planetary Science
- ❖ Resource Mapping
- ❖ Asteroid Prospecting

EXTRA-SOLAR OUTER SOLAR SYSTEM & INTERSTELLAR

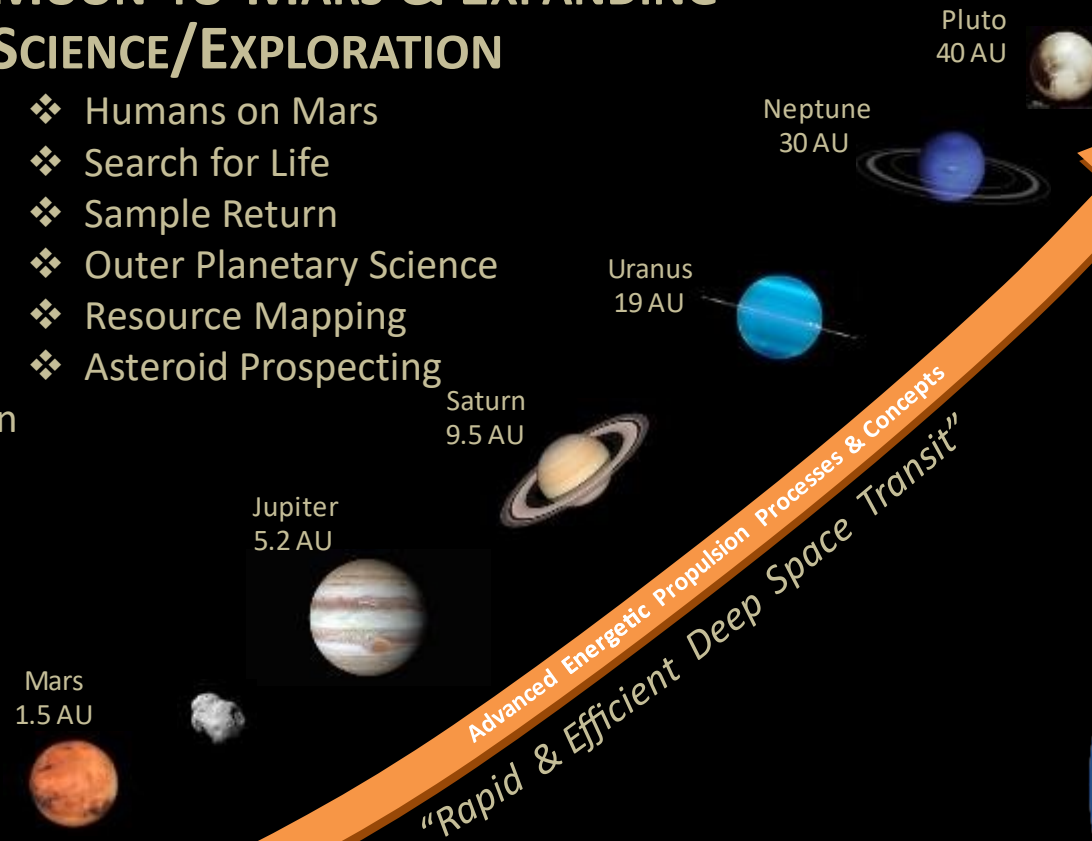
- ❖ KBOs & Primitive Bodies >50 AU
- ❖ Heliosphere / Local ISM 100-200 AU
- ❖ Pristine ISM 200-400 AU
- ❖ Solar Gravity Lens 500-800 AU
- ❖ Nearby Stars / Exoplanets 4.5-20 LY

"Commercially Sustained Cis-Lunar Infrastructure"



CP | SEP | NTP | NEP

"Littoral & Blue Water Mobility Analog"



STMD STRATEGIC FRAMEWORK ENVISIONED FUTURE

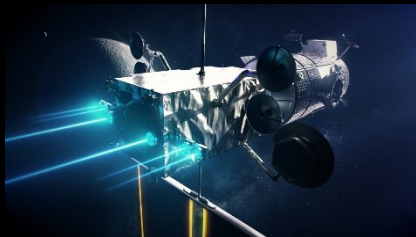
GO Thrust – Advanced Propulsion Vision



Produce advanced propulsion technologies that enable future exploration/science/commercial missions
Developing advanced propulsion technologies to push the cutting edge farther and faster than ever before

ARCHITECTURE DRIVEN PROPULSION TECHNOLOGIES

SCIENCE/EXPLORATION/COMMERCE/SECURITY CAPABILITIES



High-ΔV EP Spacecraft

High-ΔV XX-kWe EP Capability

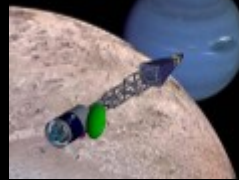
- 12-kWe Class HET → Gateway/PPE SEP
- 7-14-kWe Class GIT → Advanced NEXT
- 100-kWe Class Electric Thrusters including HET, MPD, VASIMR, & other options → Mars Transportation System



High-ΔV ESPA-Class Deep Space Spacecraft

Small Spacecraft Science, Commercial & Security Missions Requiring High-ΔV EP Capability

- Focus on ESPA-Class Sub-kW EP
- Flight Qualify & Demonstrate
- SMD SIMPLEx Mission Infusion



Outer Planetary Robotic NEP Spacecraft

Deep Space Nuclear Flagship Capabilities

- Propulsion Technologies Enabling Nuclear Propulsion Robotic Spacecraft
 - Fission Surface Power Derived NEP
 - Dynamic-RPS Derived NEP
 - Advanced LCF Derived NEP



Green Propellant Deep Space Spacecraft

Green Propellant Adoption & Infusion into Missions of Opportunity

- Facilitate Provider/User Transition
- Incentivize Mission Opportunities
- Lunar Flashlight Mission Infusion



Earth Pole Sitting Observatories Sun Pole Sitting Observatories

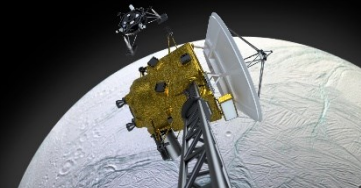


Observational Platforms for Science, Commercial & Security Missions Requiring Unlimited ΔV Capability

- Solar Sail Development & Demonstration
 - Monitor Solar Cruiser Project
 - Supplement SMD Technology Development as Warranted
 - Support Early-Stage Concept R&D



Thruster Advancement for Low Temperature Ops in Space



Deep Space Science Missions Requiring Cold Tolerant Storable Propulsion for Extreme Environments Access

- MON-25/MMH Bipropellant Thruster Technology
- Compact Lander Propulsion – TALOS → CLPS Infusion
- Deep Space Variant – Extensible TALOS → Enceladus

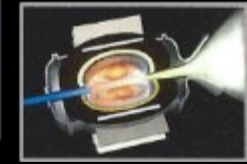
INSPIRATION DRIVEN RESEARCH

TRANSFORMATIONAL CAPABILITIES

Sustained investment in Advanced Energetic Propulsion research & innovation enables the possibility for new breakthrough technologies



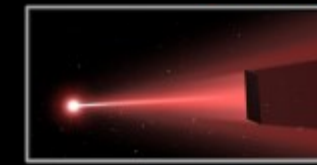
Low-α NEP



Fission Gas Core or Advanced Solid Core



Pulsed Fission



Directed Energy & Sails



Fusion



Antimatter



Breakthrough Science

Capability Goals:

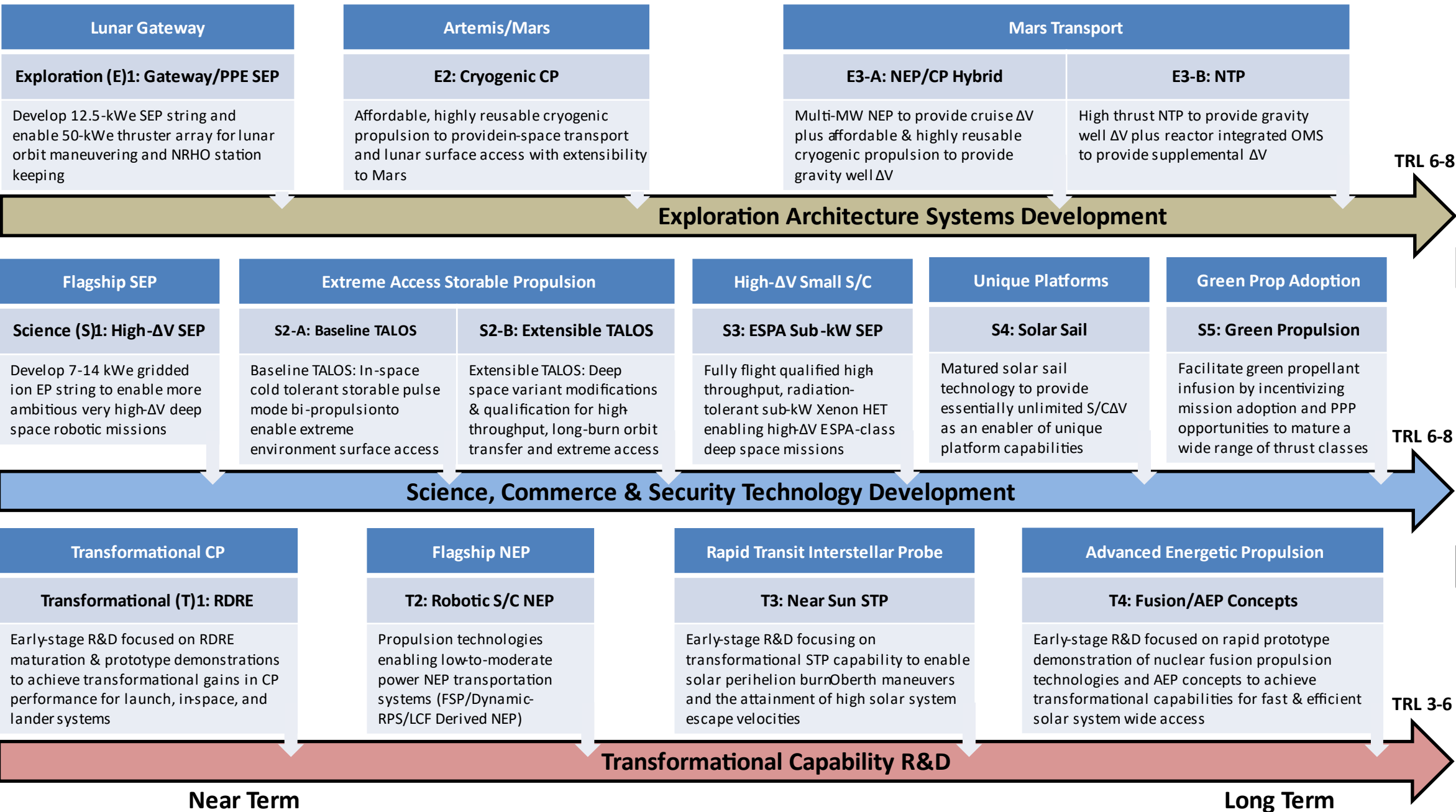
- $\alpha \leq 5 \text{ kg/kW}$
- Thrust-to-Weight ≥ 0.6
- Relativistic S/C Velocity $\geq 0.1c$

All activities depicted not currently funded or approved. Depicts “notional future” to guide technology vision.



ADVANCED PROPULSION CAPABILITY OUTCOMES

Propulsion Technology Development Streams



EXPLORATION ARCHITECTURES

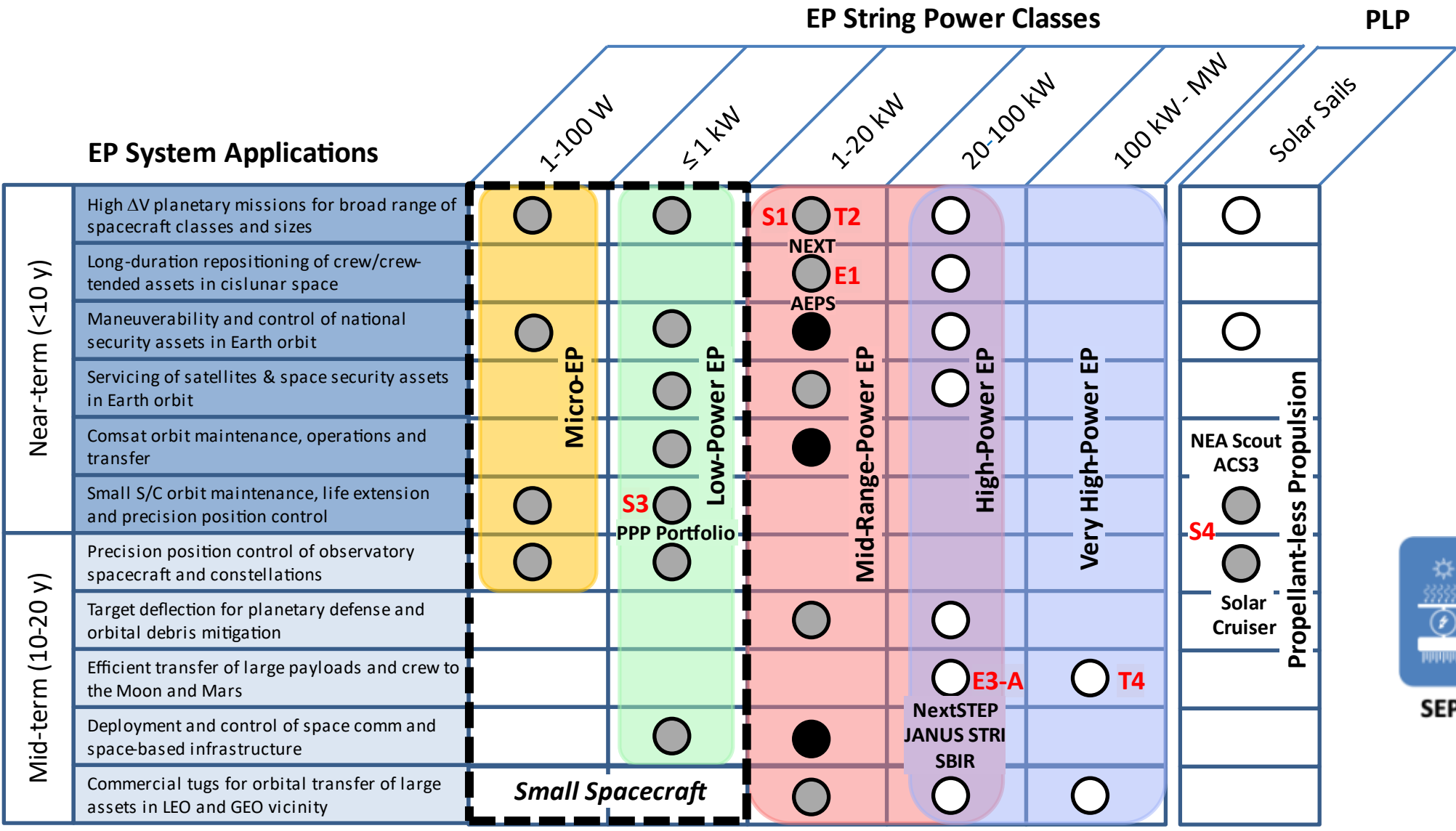
SCIENCE, COMMERCE & SECURITY

INSPIRATION DRIVEN RESEARCH



SOA – ELECTRIC PROPULSION SYSTEMS

Historical Developments & Projected Capabilities



Note: Not all developments are NASA funded

● Flight systems available ○ Development Underway to meet Application Requirements. ○ Significant Development / Requirements not Defined

Technology Objective Index	
E1	Gateway/PPE SEP
E2	Cryogenic Propulsion
E3-A	Mars NEP/CP Hybrid
E3-B	Mars NTP
S1	High-ΔV SEP
S2-A	Baseline TALOS
S2-B	Extensible TALOS
S3	ESPA Sub-kW SEP
S4	Solar Sail Propulsion
S5	Green Propellant
T1	RDRE Propulsion
T2	Flagship NEP
T3	Interstellar Probe STP
T4	Fusion/AEP

Technology Elements

SEP

NEP

AEP

PLP

P&D

AMSM



SOA – CHEMICAL & THERMAL PROPULSION SYSTEMS

Historical Developments & Projected Capabilities



Thermal Propulsion Families

In-Space CP Applications

		Solid Propellant (Ispvac=275 – 290 s)	Hydrocarbon /Hybrid (Ispvac=320 – 340 s)	LOX/LCH4 (Ispvac=340 – 365 s)	LOX/LH2 (Ispvac=415 – 445 s)	MON/MMH (Ispvac=315 – 340 s)	Green Monoprop (Ispvac=220 – 250 s)	NTP/STP – LH2 (Ispvac=900 – 1000 s)	RDRE (≥5% Increase Ispvac)
High Thrust (Pump-Fed)	Large ΔV, Fixed Thrust Surface Ascent								Interagency RDRE Council
	Large ΔV, Variable Thrust Descent, Hover & Landing								T1
	Limited ΔV, Fixed Thrust In-Space Transfer						E3-B		RDRE STRG/ACO Portfolio
Low-to-Moderate Thrust (Pressure-Fed)	Large ΔV, Fixed Thrust Surface Ascent	Mars Sample Return		Cryogenic Propulsion Industry Capabilities				SNP Project	
	Large ΔV, Variable Thrust Descent, Hover & Landing								
	Reaction/Attitude Control Systems						Lunar Flashlight		
	Limited ΔV, Fixed Thrust In-Space Transfer			E2 Artemis/HLS	S2-A / S2-B TALOS		Low MON Heritage GPIM	S5 Interstellar Probe APL IRAD	T3

Technology Objective Index

- E1 Gateway/PPE SEP
- E2 Cryogenic Propulsion
- E3-A Mars NEP/CP Hybrid
- E3-B Mars NTP
- S1 High-ΔV SEP
- S2-A Baseline TALOS
- S2-B Extensible TALOS
- S3 ESPA Sub-kW SEP
- S4 Solar Sail Propulsion
- S5 Green Propellant
- T1 RDRE Propulsion
- T2 Flagship NEP
- T3 Interstellar Probe STP
- T4 Fusion/AEP

Technology Elements



CP



STP



NTP



CFM



AMSM

Note: Not all developments are NASA funded



Flight System Available



Flight System Out of Production



Development Underway to meet
Application Requirements



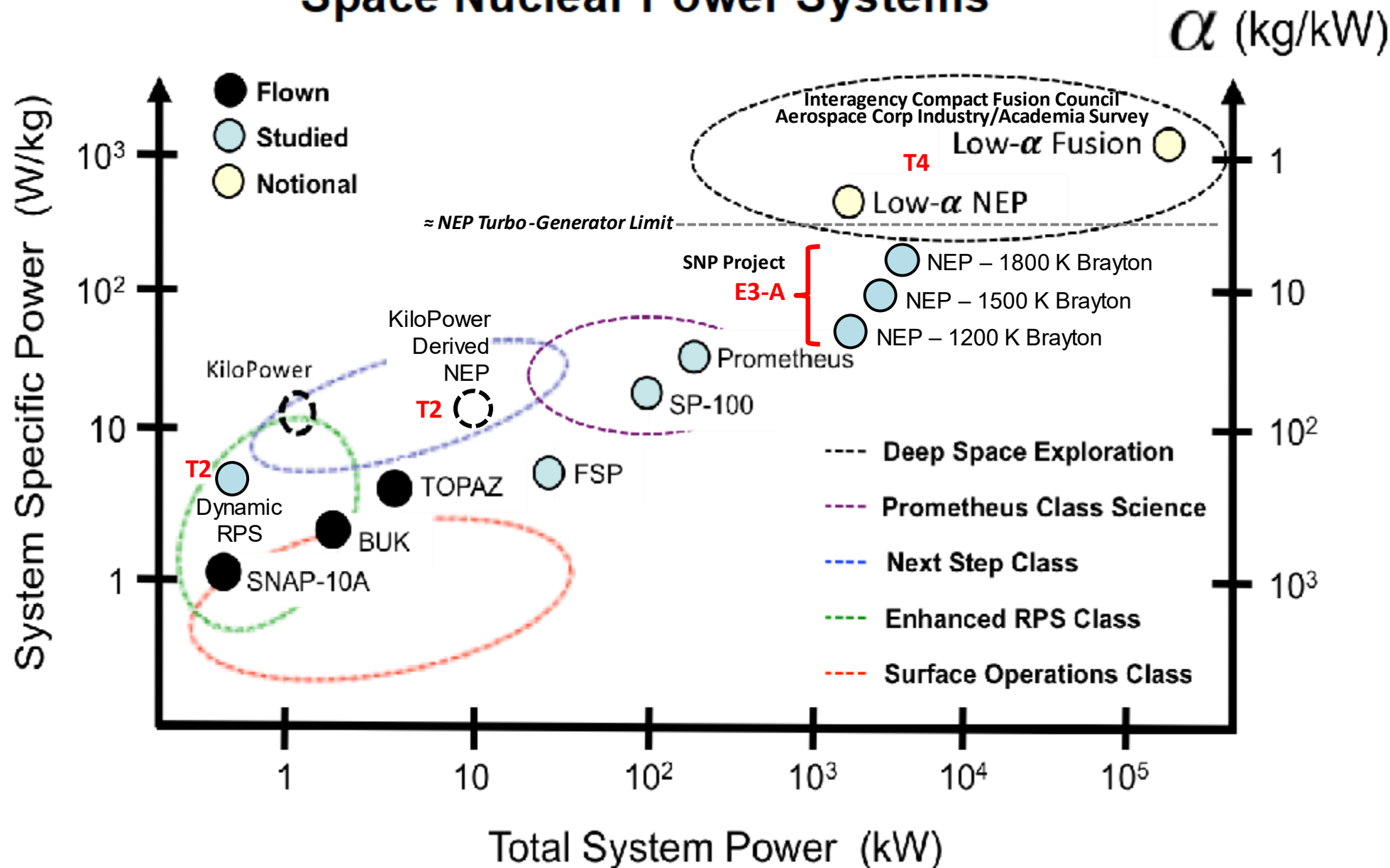
Significant Development /
Requirements Not Defined

SOA – SPACE NUCLEAR PROPULSION & POWER SYSTEMS

Historical Developments & Projected Capabilities



Space Nuclear Power Systems



Technology Objective Index

- E1 Gateway/PPE SEP
- E2 Cryogenic Propulsion
- E3-A Mars NEP/CP Hybrid
- E3-B Mars NTP
- S1 High- ΔV SEP
- S2-A Baseline TALOS
- S2-B Extensible TALOS
- S3 ESPA Sub-kW SEP
- S4 Solar Sail Propulsion
- S5 Green Propellant
- T1 RDRE Propulsion
- T2 Flagship NEP
- T3 Interstellar Probe STP
- T4 Fusion/AEP

Technology Elements



NEP



AEP



P&D



AMSM



CONCLUSIONS & HIGH LEVEL DEVELOPMENT STRATEGY

- **Architecture Driven Propulsion Technology Strategy is Essentially On Track**
 - Emphasis on sustained portfolio execution & commitment to deliveries, including accommodation of ground infrastructure impacts
 - Additional mid-TRL investment is needed in a few priority areas (e.g., ESPA-Class Sub-kW EP & Beyond NextSTEP High-Power EP)
- **Transformational Capability R&D Portfolio in need of Programmatic Restructuring & Significant Funding Augmentation**
- **High Level Development Strategy**

Architectural Outcome	Technology Capability Goal	Recommended Action	Investment Trend
Gateway/PPE SEP	12 kWe HET String / 50 kW SEP System	Sustain Execution & Commitment to PPE/Gateway Delivery	Sustain
Flagship High-ΔV SEP	7-14 kWe Gridded Ion EP String	Develop Advanced NEXT via Interagency Collaboration + SBIR + PPP	Augment
High-Power Exploration NEP	100 kWe HET, MPD, VASIMR, etc.	Industry Led Development/Qual via STRG + SBIR + PPP (i.e., Beyond NextSTEP)	Augment
ESPA-Class High-ΔV SEP	0.5-1 kWe (nominal) EP String	Industry Led Development/Qualification/Demo via SST/GCD PPP	Augment
Extreme Cold Environment CP	Baseline MON25/MMH TALOS	Sustain Execution & Commitment to PPP CLPS Delivery	Sustain
	Deep Space Variant TALOS	Commit to Industry Led Development/Qualification via PPP	Augment
Green Propellant CP	Reduced Cost / Expanded Thrust Range	Facilitate Infusion & Industry Led Development via SBIR/STTR + PPP + Incentives	Sustain
Unlimited ΔV Platforms PLP	Flight Demonstrated Solar Sail Technology	Monitor Solar Cruiser + Supplemental Tech Dev + SBIR/STTR + Early-Stage R&D	Sustain
RDRE CP	Transformative CP Performance	Sustain Early-Stage R&D & Transition to FY23 Mid-TRL Prototype Development	Augment
Flagship NEP	Transformative Robotic Science NEP	Evaluate/Facilitate FSP/Dynamic-RPS/LCF NEP System Integration & Maturation	Augment
Interstellar Probe Near Sun STP	Transformative Near Sun STP Capability	Sustain Early-Stage R&D & Transition to FY23 Mid-TRL Prototype Development	Augment
Fusion/AEP Concepts	Transformative Fusion/AEP Capability	Establish Comprehensive Nuclear Fusion/AEP Early-Stage R&D Portfolio	Augment



ADVANCED PROPULSION TECHNOLOGY DOMAIN

Taxonomy & Acronym Glossary



PROPULSION TECHNOLOGIES



CP



STP



SEP



NEP



NTP

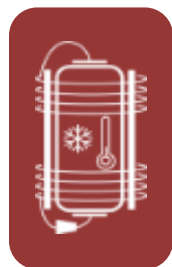


PLP



AEP

CROSS-CUTTING SUPPORT TECHNOLOGIES



CFM



AMSM



P&D

AEP – Advanced Energetic Propulsion
ACO – Announcement of Collaborative Opportunity
ACS – Attitude Control System
AMSM – Advanced Materials, Structures & Manufacturing
AU – Astronomical Units
BUK – Soviet Era Fast Fission Space Reactor (Derived from Bouk → “Beech Tree”)
CP – Chemical Propulsion
c – Speed of Light
CFM – Cryogenic Fluid Management
CLPS – Commercial Lunar Payload Services
EML1 – Earth Moon Lagrange Point 1
Enceladus – Icy Moon of Saturn
EP – Electric Propulsion
ESPA – Evolved Secondary Payload Adaptor
FSP – Fission Surface Power
GCD – Games Changing Development (Program)
GEO – Geo Synchronous Orbit
GIT – Gridded Ion Thruster
GPIM – Green Propulsion Infusion Mission
GTO – Geo Transfer Orbit
HET – Hall Effect Thruster
HLS – Human Landing System
IRAD – Internal R&D
ISM – Interstellar Medium

ACRONYMS

Ispvac – Vacuum Specific Impulse
LCF – Lattice Confined Fusion
LEO – Low Earth Orbit
LLO – Low Lunar Orbit
LOX – Liquid Oxygen
LY – Light Year
MMH – Mono-Methyl Hydrazine
MON – Mixed Oxides of Nitrogen
MPD – Magneto Plasma Dynamic (Thruster)
MPS – Main Propulsion System
NASA – National Aeronautics and Space Administration
NEA – Near Earth Asteroid
NEO – Near Earth Object
NEP – Nuclear Electric Propulsion
NEXT – Next Evolutionary Xenon Thruster
NRHO – Near Rectilinear Halo Orbit
NTP – Nuclear Thermal Propulsion
PLP – Propellant-Less Propulsion
PPE – Propulsion & Power Element (Foundational Gateway)
PPP – Public Private Partnership
PPU – Power Processing Unit
P&D – Power & Distribution
R&D – Research & Development
RCS – Reaction Control System
RDRE – Rotating Detonation Rocket Engine
RPS – Radioisotope Power System
SBIR – Small Business Innovation Research (Program)

S/C – Spacecraft
SEP – Solar Electric Propulsion
SIMPLEx – Small Innovative Missions for Planetary Exploration
SMD – Science Mission Directorate
SOA – State of Art
SNAP-10A – System for Nuclear Auxiliary Power
SNP – Space Nuclear Propulsion (Project)
SP-100 – Space Reactor Prototype
SST – Small Spacecraft Technology (Program)
STP – Solar Thermal Propulsion
STRG – Space Technology Research Grants
STTR – Small Business Technology Transfer
TALOS – Thruster Advancement for Low Temperature Operations in Space
TDM – Technology Demonstration Mission (Program)
TOPAZ – Soviet Era Thermal Fission Space Reactor
TP – Tipping Point
TRL – Technology Readiness Level
T/W – Thrust-to-Weight (ratio)
VASIMR – Variable Specific impulse Magnetoplasma Rocket
ZBO – Zero Boil Off
 α – System Specific Mass (kg/kW)
 ΔV – Spacecraft Velocity Change